Senior Thesis

Variations in the Brine Chemical Composition of the Oriskany Sandstone of Ohio

by
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TABLE OF CONTENTS

ABSTRACT

The Na and Mg concentrations of 24 brine samples of the Oriskany Sandstone in eastern Ohio are the result of subsurface mixing of at least two distinctively different brine components. In addition the concentrations of conservative elements in the Mg-rich and the Na-rich brines were altered by dilution.

The concentrations of major elements (Ca, Mg, K, and Na) in the brine of the Oriskany Sandstone of eastern Ohio vary regionally depending on the location of the brine sample. The concentrations of the major elements also vary with depth below the surface and are the result of mixing of two brine components whose chemical compositions were affected by chemical reactions with the rocks they interacted with before entering the Oriskany Sandstone.

INTRODUCTION

The concentrations of the constituents dissolved in oilfield waters are dependent upon the origin of the water and the chemical reactions in which the water has participated in the subsurface environment. Subsurface brines may originate (1) as meteoric water that percolated into the subsurface and reacted with rocks along its path; or (2) as interstitial seawater (connate water) trapped during original sediment deposition. In either case, the water undergoes chemical changes as it evolves into brine and acquires distinctive chemical compositions that differ from the original meteoric or connate water. (COLLINS, 1975) The chemical composition of brines derived from seawater can be affected by evaporation either at the surface or at depth and by at least one of three major processes; (1) Dilution with meteoric or waters that have entered the reservoir as recharge, (2) Water-rock interactions including solution of soluble minerals, ion exchange, oxidation, and osmotic effects, (3) Mixing of different brines having contrasting chemical compositions.

The purpose of this paper is (1) to study the chemical variations in the brine of the Oriskany Sandstone of eastern Ohio to determine what reactions the brine may have been affected by before entering its final resting place in the Oriskany Sandstone; (2) to test the hypothesis that variations in the Na and Ca concentrations of the Oriskany brine in eastern Ohio are the result of mixing of at least two distinctively different brine components followed by the dilution of the resulting mixture with varying amounts of meteoric water.

Changes in the concentration of ions in oilfield brines may also be caused by contamination with fresh water used in hydrofracturing of hydro-carbon bearing strata or by faulty well casings and seals that permit groundwater to leak into producing well. Additionally, brines may be contaminated with meteoric water in storage tanks or as a result of inappropriate collecting techniques. (LOWRY *et al.,* 1987)

GENERAL GEOLOGY

The Oriskany Sandstone derives its name from the Oriskany Falls in New York where it is exposed at the surface. The name was applied by James Hall in his third annual report to the New York Geological Survey in 1839. In succeeding years, associated beds carrying an Oriskany fauna were added, making it a group rather than a single formation. Other names the Oriskany once carried include the "Niagara Sand", the "Jefferson Sand", "Cambridge gas sand", "Monroe Lime", and the "Ridgley Sandstone" in West Virginia. (LOCKETT, 1937)

In Ohio, the Oriskany Sandstone, which is Early Devonian in age, does not crop out anywhere in the state. The sandstone has been described only on the basis of well samples. The Oriskany is generally identified by well drillers within the First Water of the "Big Lime". The Big Lime includes the Onondaga Formation, the Bois Blanc Formation, the Oriskany Sandstone, the Helderberg Limestone, the Bass Islands

Dolomite, and various units of salts in southeastern Ohio. In northeastern Ohio, the Oriskany is overlain by the Lucas and Amherstburg Dolomites instead of the Onondaga Formation. It is also considered to lie unconformably below the Columbus Limestone.

The Oriskany Sandstone has been described as white to brownish-gray and fine to medium coarse grained. The sand grains vary from angular to sub-rounded with the larger grains being almost well-rounded.(HALL, 1952) A calcareous cement is almost invariably present, usually at the base of the formation. The accessory minerals include chert, glauconite, pyrite, barite, and sphalerite. The concentrations of heavy minerals in the Oriskany are small, generally less than 0.01% after the removal of pyrite.

The stratigraphic thickness of the Oriskany Formation ranges widely from 2 feet to 100 feet. The average thickness in Ohio is around 18 feet. On the basis of fossils in well cuttings from the Cambridge field, the Oriskany of Ohio correlates with the Oriskany outcrop area in eastern West Virginia and central Pennsylvania. The structure of the Oriskany in Ohio is generally flat-lying, with dips ranging from 30 feet to 100 feet per mile which places the sandstone 500 feet below sea level in the western part of the state and at a minus 4,500 feet in eastern Ohio. With the exception of a few broad monoclines, no pronounced structures are present. (HALL, 1952)

OCCURRENCES OF OIL AND GAS IN THE ORISKANY SANDSTONE

The first known production of oil or gas from the Oriskany Sandstone in Ohio occurred in 1899 in Ashtabula County where 1.5 barrels of oil per day were produced from a depth of 2140 feet below the surface. Gas was discovered two years later at a well located 2 miles northwest of the oil-producing well in 1900. This well yielded considerable amounts of gas with an initial rock pressure of 830 pounds. Subsequently, a well field was developed, 3 miles by 1 mile in size, with a daily production of 2,500,000 cubic feet of gas. The gas was found near the top of the sandstone unit, with salt water below, which soon destroyed the wells.

In 1922, the Ohio Fuel Supply Company decided to test the productivity of the Clinton Sandstone under a well defined surface structure. A location was chosen in the southwest quarter of Section 13 of Jackson Township in Guernsey County. The well was drilled on the crest of the Cambridge Arch. The well encountered an open flow of 8,000,000 cubic feet of gas at a depth of 3,470 feet, which was 125 feet below the top of the "Big Lime"; later determined to be the Oriskany Sandstone. The rock pressure was 1150 pounds, causing the well to freeze almost immediately. By 1925, eleven wells had been completed in this area. As a result, the field had started to "go to water" as the gas was depleted by excessive production.

During the next 25 to 30 years, several gas fields were discovered in the Oriskany Sandstone across the eastern half of the state. Starting in the middle of the state in Guernsey County in the 1920s and moving progressively north over the years. In 1927, oil and gas were found in southern Tuscarawas County in the North Salem field. In 1935, at a depth of 3,250 feet below sea level, gas was found in Columbiana County on an anticline dome. During the early 1940s pools of oil and gas were found in Boston and Richfield townships of Summit County. In 1946, an Oriskany pool was discovered in Vernon Township in Trumbull County. This field produced both oil and gas with an average open flow of 2,500,000 cubic feet at a depth of 2,100 feet below sea level. In this area, the Oriskany lies approximately 233 feet below the top of the “Big Lime”.

During the 1950s exploration moved south to discover new pools in the Oriskany. In 1951, a field was discovered in Troy Township of Athens County. The first well brought in 2,300,000 cubic feet daily at 4,222 feet below sea level. A second well was offset by 200 feet and had an initial open flow of 5,500,000 cubic feet of gas. In 1952, Washington County had wells that produced daily amounts of gas totaling 4,290,000 cubic feet.(HALL, 1952). Additional locations of oil and gas pools are listed on Table 1 below and in Table 1a of the Appendix.

	Wells					Total Gas*	Total Oil
Year	Total	Gas	Combination	Oil	Dry	MCF	Bbls
1948	37	21	0	6	10	15,540	78
1949	25	10	1	1	13	3,155	9
1950	10	2	3	0	5	483	63
1951	18	9	1	2	6	17,244	38

* initial production

Table 1. Discovery Statistics for Oriskany Sandstone Wells in Ohio from 1948-1951 (HALL, 1952)
Bbls = Barrels per hour   MCF = thousands of gallons of gas

METHODS

The chemical compositions of brine samples 1 to 4 identified on Table 2a in the Appendix were determined by either atomic absorption spectrometry (KNAPP, 1986), whereas samples numbered 5 to 24 were determined in the 1960s by gravimetric methods, also by ODNR personnel.

The total dissolved solids (TDS) were determined by weighing salts obtained by evaporation of known weights of brines. The (TDS) listed in table 2a of the Appendix are not consistent with the sum of the concentrations of the ions because of the absence of the Sr and Li concentrations. The TDS values range from 165,600 mg/L to 319,500 mg/L. Samples 19 and 22 may have been subjected to improper sampling techniques or were affected by a third brine causing them to be anomalous.

The concentrations of Ca, Mg, K, and Na were plotted versus Cl to compare the compositions of the brines in the Oriskany Sandstone to present day seawater. The concentrations of elements in seawater were plotted and a line was drawn from the origin to the seawater point. This line gives values of the concentration of the seawater that was diluted with meteoric water or was concentrated by evaporation. Therefore, this line can be used to determine whether the brines are enriched or depleted relative to sea water assuming that Cl was not lost or added to the brines.

In addition, a mixing triangle was drawn for the concentrations of Mg and Na from the 24 samples (excluding samples 19 and 22). The data were interpreted to determine the abundance of two hypothetical brine components and to estimate the extend of dilution. The results were plotted on maps of Ohio and contoured.

DISCUSSION OF THE CHEMICAL COMPOSITIONS

Calcium

The abundance of Ca in the crust of the earth is about 3.55% (FLEISCHER, 1962) This makes it the most abundant of the alkaline earth metals in the crustal rocks including limestone, dolomite, gypsum, or gypsiferous shale. The concentrations of Ca in subsurface brines generally range from about 2000 mg/L to 30,000 mg/L (COLLINS, 1975). The Ca concentrations of the Oriskany brines range from 19,000 mg/L to 49,011 mg/L (Appendix, Table 3A) and are higher in all cases than the seawater evaporation line. (Figure 1) In general, brines in the southeastern Ohio have low Ca concentrations compared to brines in northeastern Ohio. An explanation for the enrichment of the brines of the Oriskany Sandstone in Ca involves the process of dolomitization. Limestone comprises a majority of the bedrock in Ohio because the state was covered by ancient seas that have transgressed and regressed during the Paleozoic Era. These limestone layers were then subjected to chemical altering as Mg-rich brines percolated through them. As dolomite forms, Ca is replaced by Mg in the limestone. Hence the brines become enriched in Ca but are depleted in Mg.

Dolomitization occurs as following:

$$2CaCO_3 + Mg^{2+} \Leftrightarrow CaMg(CO_3)_2 + Ca^{2+}$$

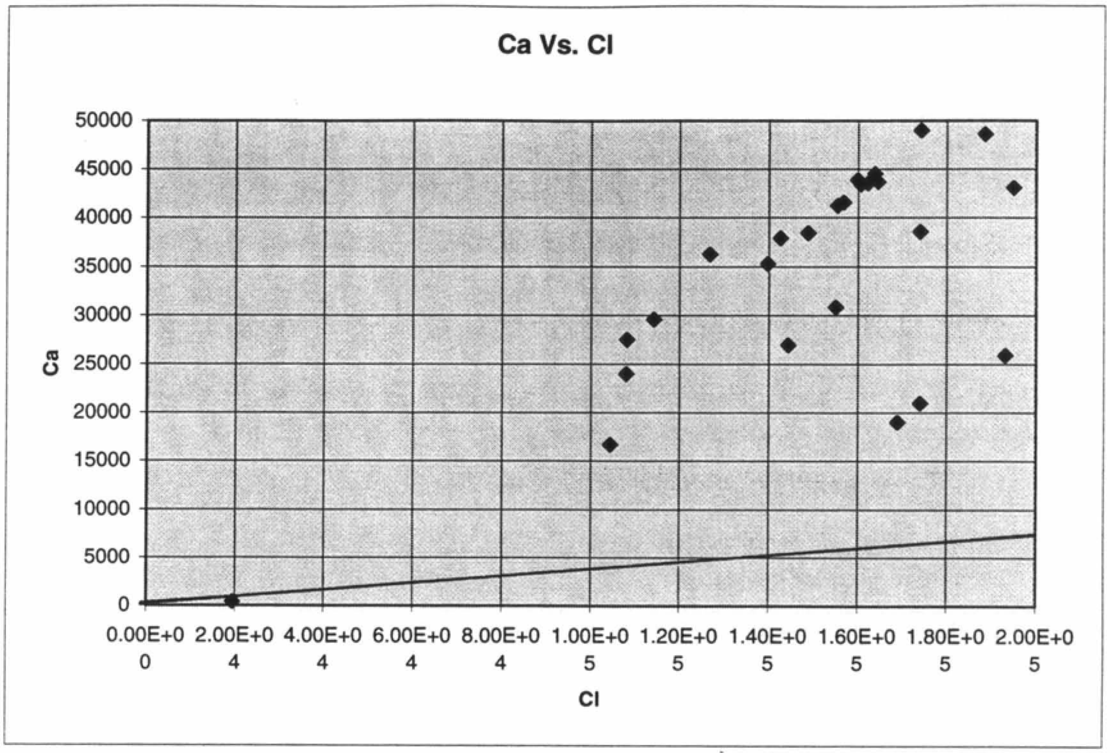

Figure 1. Plot of Ca versus Cl
Line originating from the origin
accounts for seawater concentration
due to evaporation.

Magnesium

Magnesium is also an abundant member of the alkaline earth group of metals accounting for about 2.1 wt.% of the earth's crust. (FLEISCHER, 1962) Ferromagnesian minerals in igneous rocks and magnesium carbonate in carbonate rocks are generally considered to be the principal sources of Mg^{2+} in natural waters. Therefore, waters associated with either granite or siliceous sand which do not contain Mg-rich minerals may contain less than 5 mg/L of magnesium, whereas those associated with either dolomite or limestone may contain over 2,000 mg/L of magnesium. (COLLINS, 1975)

Most of the Oriskany brines in Figure 2 scattered above and below the sea water evaporation line. The samples that were depleted in Mg originated from wells in Noble, Morgan, and Jefferson counties in the southeastern part of the state. In general, the brines in the northeastern and northern part of Ohio tended to scatter above and below the seawater evaporation line, whereas the brines in southeastern Ohio are significantly depleted in Mg.

Depletion of magnesium in brines is probably the result of the conversion of calcite to dolomite as disscused above.

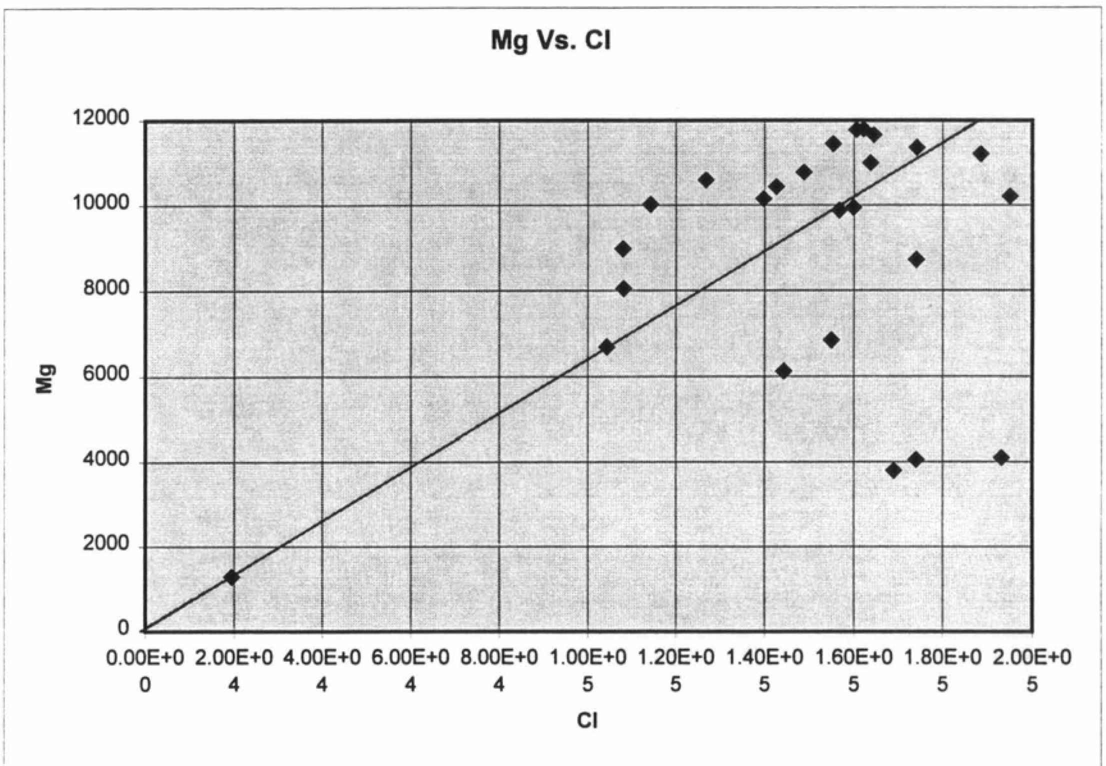

Figure 2. Plot of Mg versus Cl

Potassium

The second most abundant member of the alkali-metal group is potassium. Its abundance in the earth's crust is about 2.55%. (FLEISCHER, 1962). It occurs in igneous and metamorphic rocks in the form of feldspars and micas.

The potassium concentrations of the Oriskany brines vary widely from being slightly enriched in the northern samples in Lake and Ashtabula counties to being depleted in all of the other brine samples. (Figure 3)

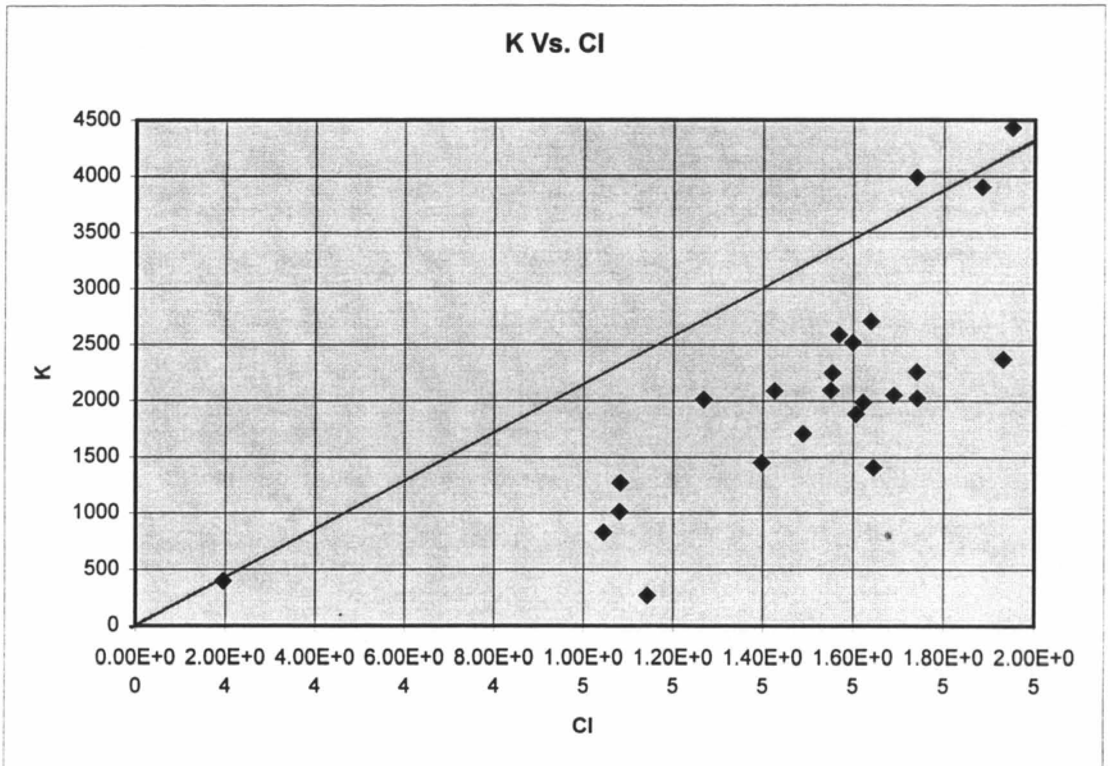

Figure 3. Plot of K versus Cl

One possible explanation for the depletion of K is the transformation of clay minerals into illite during thermal diagenesis. Another explanation for the depletion of K is the reaction of kaolinite in the basement rocks of Ohio to form microcline (MENSING, 1982). The following reaction applies to the formation of microcline:

$$Al_2Si_2O_5(OH)_4 + 2K^+ + 4H_4SiO_4 \Leftrightarrow 2KAlSi_3O_8 + 9H_2O + 2H^+$$

Sodium

The abundance of Na in the earth's crust is around 2.8 wt.%. (FLEISCHER, 1962) Sodium salts (NaCl, Na_2SO_4, and $NaHCO_3$) are all soluble and do not precipitate under normal circumstances. Sodium can be adsorbed by clay minerals, whereas Mg and K may actually enter the lattice of three-layer clays. Sea water contains around 11,000 mg/L of Na and halite begins to precipitate at Na concentrations of around 140,000 mg/L.

Figure 4 shows that the sodium concentrations of the Oriskany brines in eastern Ohio have been decreased relative to the seawater evaporative line. Since sodium does not precipitate readily from aqueous solution, the most likely reason for the depletion is of adsorption by clays in shale units.

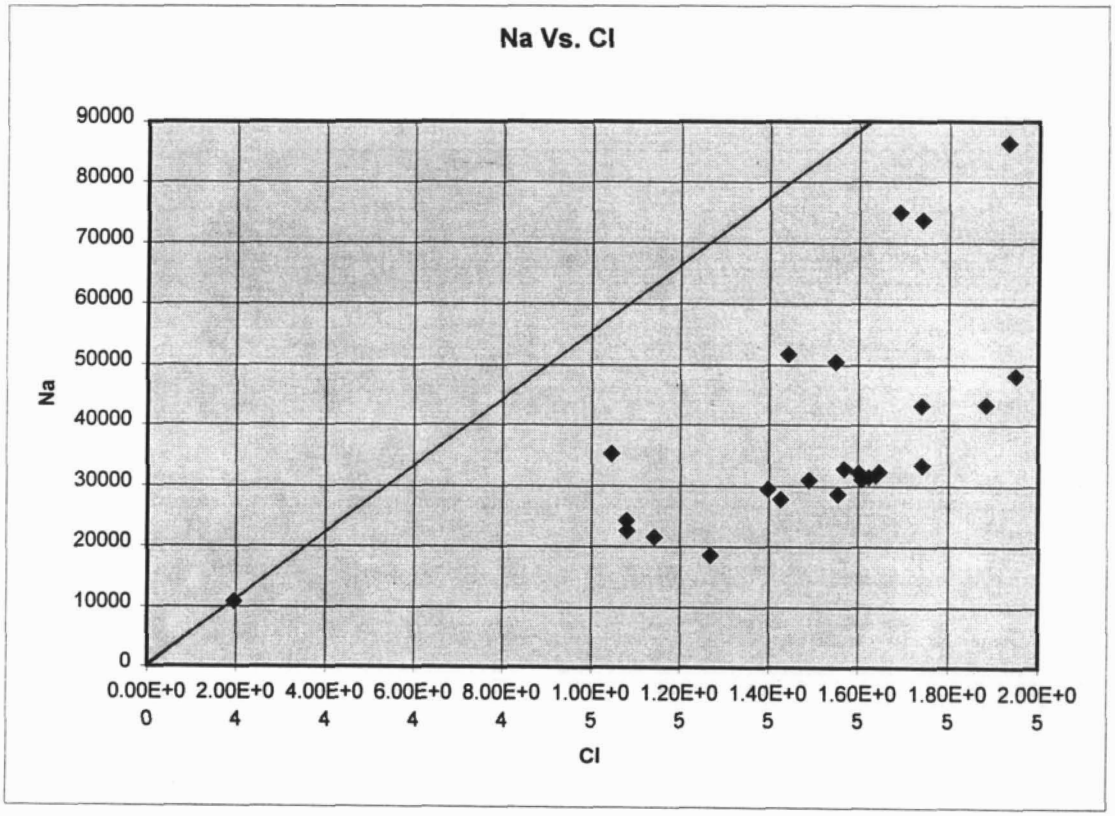

Figure 4. Plot of Na versus Cl

MIXING TRIANGLES

When a brine of constant composition is progressively diluted with groundwater or meteoric surface water, the concentrations of any two conservative elements from the brine samples form a straight line directed toward the origin. When two brines of differing compositions mix in the subsurface, and are diluted by groundwater or meteoric surface water, the resulting points are scattered within a triangle of mixing. (LOWRY *et al.*, 1987).

A mixing triangle is an x-y plot with the concentrations of element D on the y-axis and the concentrations of element C on the x-axis. Two sides of the triangle are formed by drawing a line from the origin to the end members labeled brines A and B. The mixing line, the far side of the triangle, is formed by connecting the end points that are defined by brines A and B. The mixing triangle is then used to estimate the concentrations of C and D in brines samples after removing the effect of dilution.

Mixing

To determine the abundances of components A and B in a given sample, a line is drawn from the origin through the point in question (sample point Q on Figure 5) to the intersection with the mixing line. To determine the concentration of brine A, the distance from points B to P is divided by the distance from points A to B. This ratio is the abundance of component A (f_a) in sample Q. In order to determine the abundance of component B in sample Q the distance A to P is divided by the length of the line AB. If either value of f_a or f_b is known, the later can be determined by the relationship:

$$f_{(a \text{ or } b)} = 1 - f_{(a \text{ or } b)}$$

Dilution

To determine the amount of dilution in a sample, a line is drawn from the origin, through the point in question (point Q in Figure 5), to the intersection with the mixing line. The amount of dilution is indicated by the ratio of the distance QP divided by the distance OP. This ratio termed f_d.

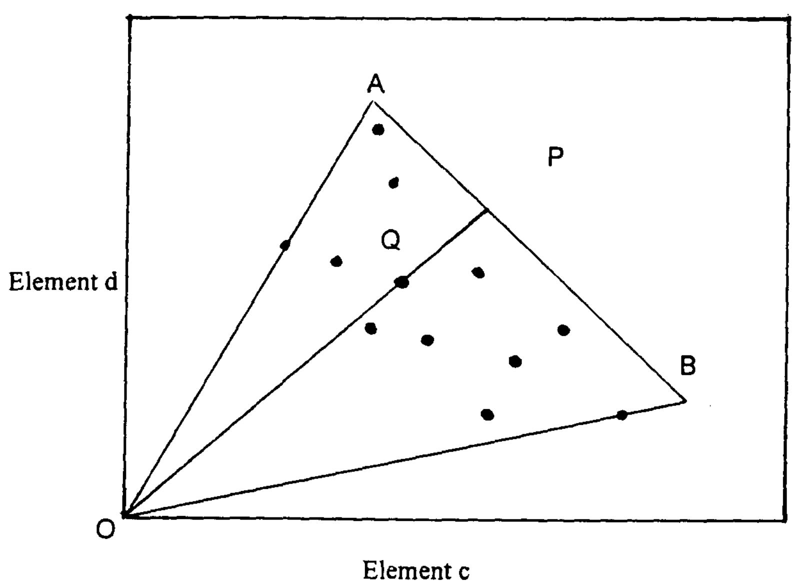

Figure 5. Sample plot of the concentrations of elements C and D of brine samples enclosed in a mixing triangle.

Na vs Mg MIXING TRIANGLE

To determine the values of F_a and F_d in eastern Ohio, the concentrations of Na were plotted against those of Mg (Figure 6).

The outermost values on both the right and left sides of the data point cluster were used to determine the sides of the mixing triangle excluding sample numbers 19 and 22 as they fell too far outside of the cluster. The last side of the triangle, the mixing line, was arbitrarily drawn so as to include as many data points in a straight line as possible on the outside of the cluster.

The F_a values were determined by extending a line from the origin through each of the 22 points to the mixing line. The distance from point B to the intersection of the mixing line of each of the 22 real data points was then divided by the total distance of the mixing line from points A to B. These values are listed on table 4A in the appendix.

The F_d values were determined by using the same extended lines from the origin through each of the 22 data points to the mixing line. Each F_d value listed on table 4A in the appendix is the ratio of the distance from the data point in question to the intersection of the mixing line divided by the total distance of the line from the origin to the mixing line.

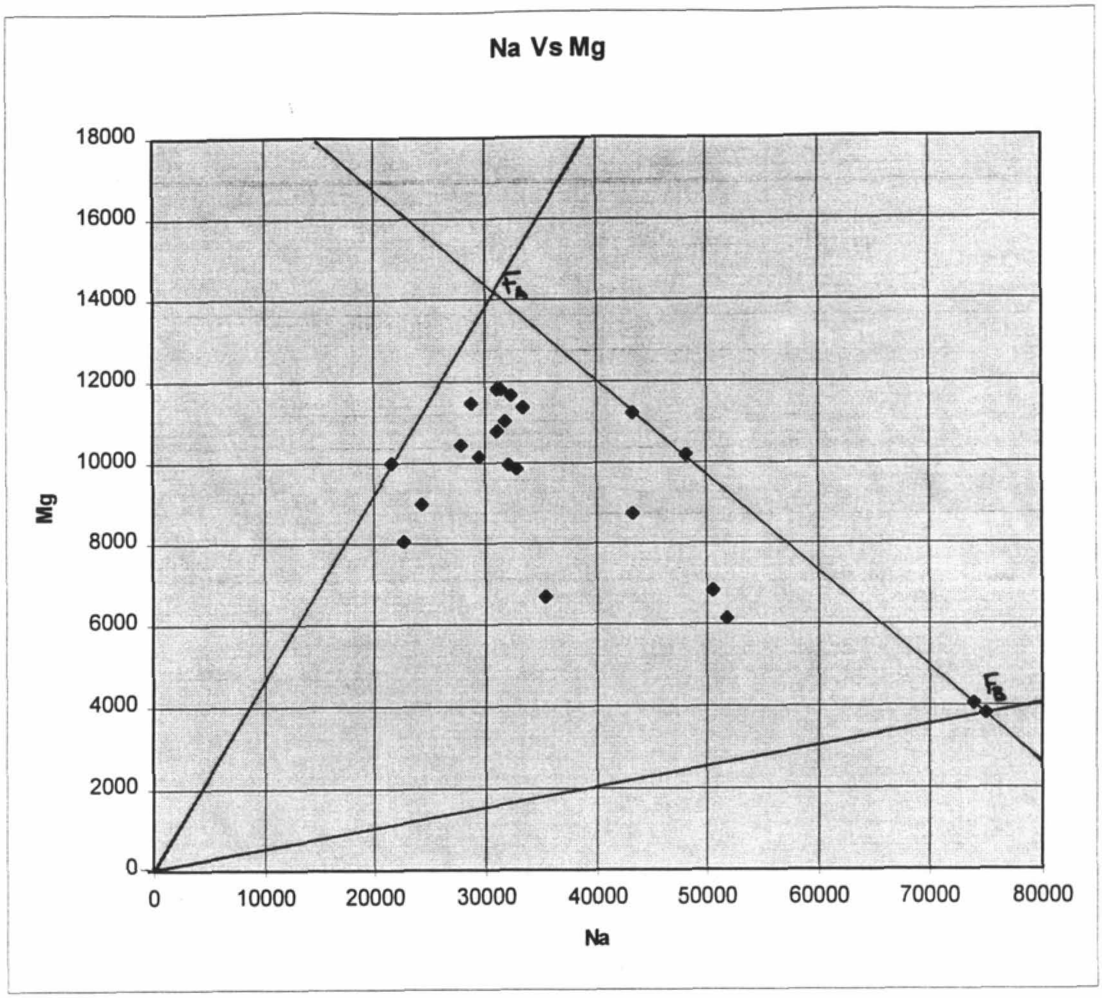

Figure 6. Mixing Diagram of concentrations of Na and Mg for the 24 brine samples

DISCUSSION OF THE MIXING TRIANGLE

By plotting the abundance of component A (f_a) in each of the 24 samples of the Oriskany brine on a map of eastern Ohio from Table 4A of the Appendix, regional trends in the abundance of this component are recognized in Figure 7.

Component A is most abundant in the middle of the state, and is enriched in Mg and Ca compared to brine B. The Mg concentrations of component A range from 6000-

12,000 mg/L while Ca values range from 25,000-50,000 mg/L. Component B is located generally in the eastern part of the state, has lower Mg concentrations that range from around 4000 - 5000 mg/L, while Ca concentrations range from around 18,000-25,000 mg/L. Conversely, Component B is the Na-rich brine with concentrations from 65,000-80,000 mg/L compared to only 20,000-40,000 mg/L Na in component A. Most of the samples in this study consist predominantly of component A as shown on Tables 4A in the Appendix.

Dilution

As expected, values of F_d in Figure 8 are highest in the middle of the state where the depth to brine is shallowest (Appendix, Table 4A) and the brines are more susceptible to dilution by meteoric water. In eastern part of the state, where the depth to brine is significantly greater due to the dip of the Oriskany Sandstone, dilution approach zero.

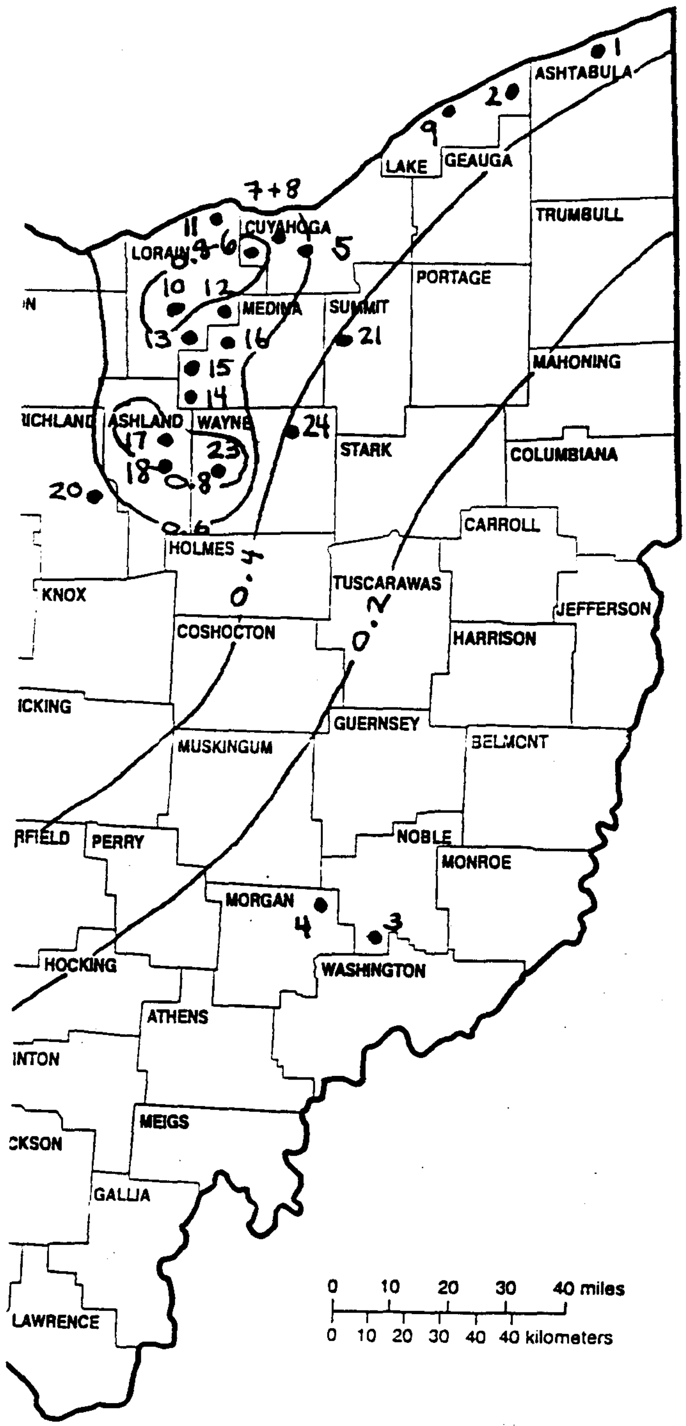

Figure 8. Contour map showing the westerly increase of F_a values within brines of the Oriskany Sandstone. Contour interval is 0.2

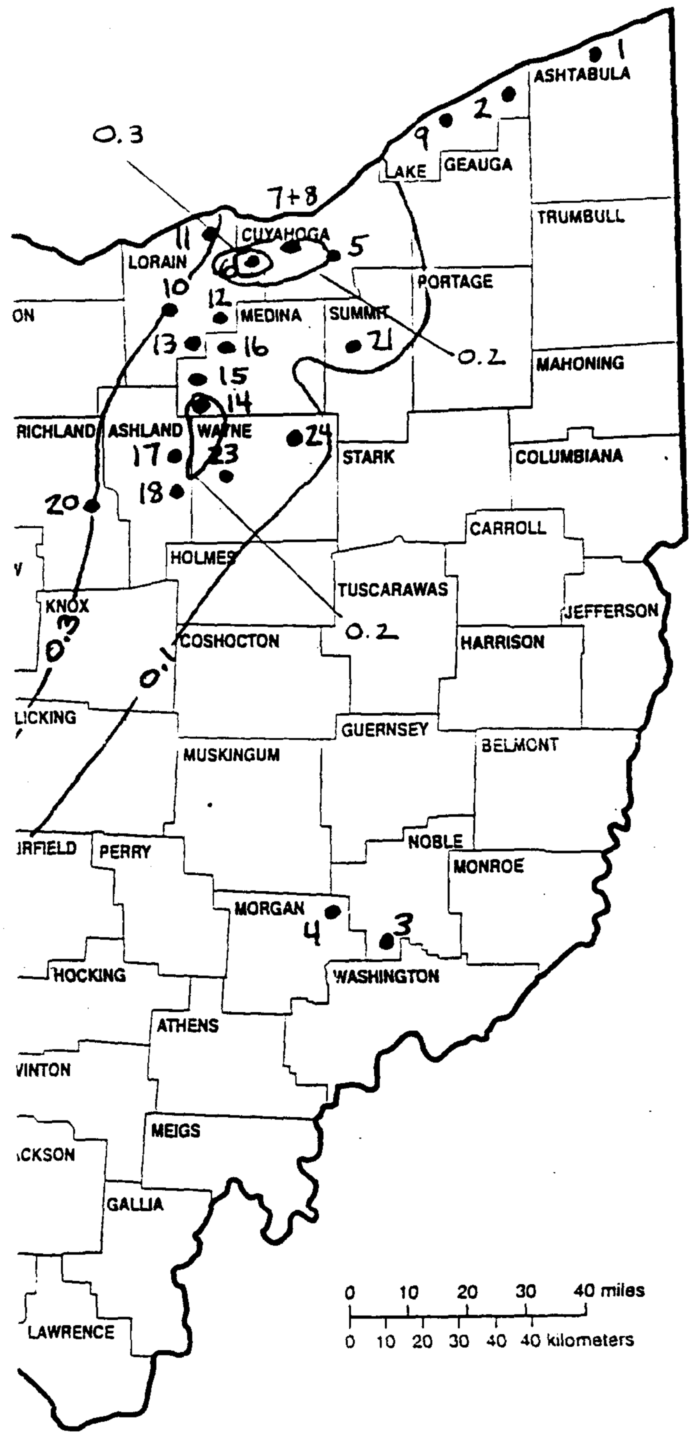

Figure 9. Contour map showing westerly increase of F_d values within the brines of the Oriskany Sandstone. Contour Interval is 0.1.

SUMMARY OF CONCLUSIONS

In the first part of this study, the concentrations of Ca, Mg, K, and Na were plotted versus chloride in an attempt to identify and explain the enrichment or depletion of these elements relative seawater evaporation line. The results show that dolomitization can account for the low concentration of Mg and high concentration of Ca of the Oriskany brines. Low potassium concentrations may result either from the uptake of K^+ by clay minerals or by the conversion of kaolinite to K-feldspar. The concentrations of Na are also less than those expected for seawater that has undergone evaporative concentration and may be caused by adsorption on clay minerals in shale.

Part two of this study showed that the brine in the Oriskany Sandstone of eastern Ohio is the result of subsurface mixing of two distinctive brines of different composition, a Mg and Ca-rich brine and a Na-rich brine. In addition, the data revealed that the brines were diluted by meteoric water in certain areas of Ohio where the Oriskany occurs at relatively shallow depth.

APPENDIX

Data Tables for the Oriskany Brines

Pool Name	County	Oil or Gas	Type Accumlation	Discovery Date
Conneaut	Ashtabula	Gas	*	1929
Saybrook	Ashtabula	Gas	*	1915
Austinburg	Ashtabula	Gas	*	1899
Eaglesville	Ashtabula	Gas	*	1919
Geneva	Ashtabula	Gas	*	unknown
Madison Lake	Lake	Gas	*	1920
Mentor	Lake	Gas	*	1915
Concord	Lake	Gas	*	1902
Mayfield	Cuyahoga	Gas	*,#	1941
Parma	Cuyahoga	Gas	*,#	1948
Boston	Summit	Oil-Gas	*	1948
Hinckley-Granger	Summit-Medina	Gas	*	1941
Ghent	Summit	Gas	*	1946
Vernon	Trumbull	Oil-Gas	*	1946
Knox	Mahoning-Columbiana	Gas	*,#	1944
Madison -Columbiana	Columbiana	Gas	*	1946
Jenkins-Columbiana	Columbiana	Gas	*	1935
Green-Jackson	Stark-Summit	Gas	*	1934
Sandyville	Stark-Tuscarawas	Gas	*	1943
Franklin	Tuscarawas	Gas	*	aprrox 1937
Paint	Holmes	Gas	*	1941
Bolivar	Tuscarawas	Gas	*	approx 1937
Beartown	Tuscarawas	Gas	*	approx 1937
Richland	Holmes	Gas	*	1941
Gilmore	Tuscarawas	Gas	*	1930
North Salem	Tuscarawas-Guernsey	Oil-Gas	*	1927
Connesville	Coshocton	Gas	*	1929
Birds Run	Guernsey	Gas	*	1926
Knox	Guernsey	Gas	*	1925
Cambridge	Guernsey	Oil-Gas	*	1922
Norwich-Philo	Muskingum	Oil	*	1930
Belpre-Troy	Athens-Washington	Gas	*	1951

* = Stratigraphic Trap
# = Structural Trap

Table 1A. Oriskany Sandstone Gas and Oil Pool Locations (HALL, 1952)

study #	sample #	County	Township	Section	Lot	Permit #	Depth to brine(ft)
1	Br 65-88	Ashtabula	Ashtabula	-----	-----	-----	-----
2	Br 66-88	Lake	Madison	-----	9	709	1631
3	Br 99-89	Noble	Jackson	-----	-----	3477	4301
4	Br 100-89	Morgan	Manchester	4	-----	2545	3814
5	42254-5	Cuyahoga	Parma	-----	-----	-----	1820
6	49058-18	Cuyahoga	Olmsted	-----	-----	-----	1473
7	w15	Cuyahoga	Westlake	-----	-----	-----	1340
8	w16	Cuyahoga	Westlake	-----	-----	-----	1310
9	w244	Lake	Painesville	-----	-----	-----	1915
10	155-18	Lorain	Carlisle	-----	-----	-----	1374
11	w57	Lorain	Avon	4	-----	-----	1150
12	238-31	Lorain	Columbia	-----	-----	-----	1540
13	w58	Lorain	Graften	-----	95	-----	1625
14	247-36	Medina	Homer	17	-----	-----	1820
15	245-34	Medina	Litchfield	-----	48	-----	1740
16	216-25	Medina	Liverpool	-----	-----	-----	1795
17	138-3	Ashland	Jackson	11	-----	-----	2010
18	246-37	Ashland	Perry	15	-----	-----	1980
19	204-21	Jefferson	Island Creek	NW 26	-----	-----	5165
20	234-29	Richland	Mifflin	NE 21	-----	-----	2005
21	239-32	Summit	Bath	-----	85	-----	2140
22	w287	Summit	Macedonia			-----	-----
23	145-12	Wayne	Chester	SW 17	-----	-----	2140
24	w243	Wayne	Milton	12	-----	-----	2272

Table 2A. Locations of Oriskany Sandstone Brines Samples of Eastern Ohio

Table 3A Chemical Analyses of Oriskany Sandstone Brines in Eastern Ohio

study #	sample #	Na (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Cl (mg/L)	Specific Gravity	TDS
1	Br 65-88	43300	38600	3990	8720	174000	1.1940	284900
2	Br 66-88	48200	43100	4430	10200	195000	1.2167	319500
3	Br 99-89	75000	19000	2050	3790	169000	1.1861	285000
4	Br 100-89	73800	21000	2260	4040	174000	1.1917	292700
5	48854-5	32240	43880	2520	9930	159880	1.1810[1]	252210
6	49058-18	22600	27520	1270	8050	108180	1.1283[1]	171260
7	w15	31060	38460	1710	10770	148880	1.1691[1]	235350
8	w16	29560	35300	1450	10150	139690	1.1625[1]	220480
9	w244	43400	48600	3900	11200	188400	-----	295700
10	155-18	21632	29584	267	10016	114247	1.1250[2]	177700
11	w57	24350	24013	1012	8977	108016	1.1250[2]	168750
12	238-31	32422	43716	1409	11652	164519	1.1800[2]	256100
13	w58	28689	41244	2250	11441	155372	1.1800[2]	241900
14	247-36	27853	37946	2091	10431	142591	1.1590[2]	224800
15	245-34	31877	44556	2706	11004	163846	1.1820[2]	257700
16	216-25	33449	49011	2024	11350	174137	1.1939[2]	273500
17	138-3	31149	43407	1884	11781	160592	1.1779[2]	251200
18	246-37	32898	41586	2591	9872	156767	1.1750[2]	246520
19	204-21	86422	25888	2370	4078	193105	1.2110[2]	316100
20	234-29	35356	16725	828	6690	104460	1.1150[2]	165600
21	239-32	50460	30844	2097	6835	154984	1.1750[2]	246750
22	w287	18500	36300	2010	10590	126770	1.1511[1]	197550
23	145-12	31486	43549	1988	11785	162210	1.1790[2]	252900
24	w243	51787	26945	negligible	6124	144339	1.1640	231090

1 = determined at 15.5 C°

2 = determined at 15.0 C°

study #	sample #	Na (mg/L)	Mg (mg/L)		County	Township		fa		fd
1	Br 65-88	43300	8720		Ashtabula	Ashtabula		0.44		0.12
2	Br 66-88	48200	10200		Lake	Madison		0.45		0.00
3	Br 99-89	75000	3790		Noble	Jackson		0.00		0.00
4	Br 100-89	73800	4040		Morgan	Manchester		0.02		0.00
5	48854-5	32240	9930		Cuyahoga	Parma		0.60		0.19
6	49058-18	22600	8050		Cuyahoga	Olmsted		0.90		0.38
7	w15	31060	10770		Cuyahoga	Westlake		0.64		0.16
8	w16	29560	10150		Cuyahoga	Westlake		0.63		0.21
9	w244	43400	11200		Lake	Painesville		0.52		0.01
10	155-18	21632	10016		Lorain	Carlisle		1.00		0.30
11	w57	24350	8977		Lorain	Avon		0.66		0.32
12	238-31	32422	11652		Lorain	Columbia		0.65		0.11
13	w58	28689	11441		Lorain	Graften		0.69		0.16
14	247-36	27853	10431		Medina	Homer		0.67		0.21
15	245-34	31877	11004		Medina	Litchfield		0.64		0.14
16	216-25	33449	11350		Medina	Liverpool		0.63		0.11
17	138-3	31149	11781		Ashland	Jackson		0.91		0.12
18	246-37	32898	9872		Ashland	Perry		0.79		0.18
19	204-21				Jefferson	Island Creek		--------		--------
20	234-29	35356	6690		Richland	Mifflin		0.55		0.30
21	239-32	50460	6835		Summit	Bath		0.39		0.13
22	w287				Summit	Macedonia		--------		--------
23	145-12	31486	11785		Wayne	Chester		0.90		0.12
24	w243	51787	6124		Wayne	Milton		0.32		0.15

Table 4A. Fa and Fd values for the brine of the Oriskany Sandstone. Sample numbers 19 and 22 were determined to be anamolus and have not been included in this study.

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